AMENDMENTS TO THE CLAIMS

1. (Currently amended) A non-invasive method of obtaining at least one predetermined target soundwave field in a substantially homogeneous medium masked by a bone barrier by causing sound signals to be emitted by at least one array of transducers through said bone barrier,

the method ~~being characterized in that it comprises~~ comprising:

a training stage comprising at least the following steps:

1a) making a three-dimensional image of the bone barrier, at least in part by using X-rays, thereby obtaining a parameter representative of the porosity of said bone barrier at various points;

1b) from said three-dimensional image, determining three-dimensional maps of at least density, soundwave speed, and soundwave absorption in said bone barrier;

1c) determining a specific position for the array of transducers relative to the bone barrier;

1d) simulating at least one propagation of soundwaves between at least one point of the substantially homogeneous medium and at least some of the transducers of the array of transducers on the basis of a mathematical model of propagation and said three-dimensional maps of density, soundwave speed, and soundwave absorption; and

1e) on the basis of said simulation, calculating individual sound signals to be emitted by at least some of the transducers of said array of transducers in order to obtain said target soundwave field;

and a stage of actually positioning the array of transducers on the brain barrier, this stage comprising the following steps:

2a) initially positioning the array of transducers on the bone barrier approximately in the specific position;

2b) using at least some of the transducers of the array of transducers to perform echography to locate the position of said array of transducers relative to the bone barrier; and

2c) refining the position of the array of transducers relative to said bone barrier as a function of the location determined in step 2b); and

an imaging stage during which at least one echographic image of the substantially homogenous medium is made using at least a portion of the array of transducers, using the individual sound signals as determined during the training stage.

2. (Previously presented) A method according to claim 1, in which, during step 2b), the relative position between said array of transducers and the bone barrier is located by determining an outside shape of at least a portion of the bone barrier by echography using at least a portion of said array of transducers, and comparing said outside shape with said three-dimensional image of the bone barrier.

3. (Previously presented) A method according to claim 1, in which:

in step 1a), an initial step is performed during which a locating device is rigidly secured on said bone barrier, said locating device being adapted to absorb X-rays;

during step 1a), the three-dimensional image made also gives the position of the locating device on the bone barrier; and

during step 2b), the relative position between the array of transducers and the locating device is identified by echography.

4. (Previously presented) A method according to claim 1, in which the array of transducers is included in a fluid-filled tank having at least one flexible wall, and during the positioning stage, said flexible wall is pressed against the bone barrier.

5. (Currently amended) A non-invasive method of obtaining at least one predetermined target soundwave field in a substantially homogeneous medium comprising at least a portion of a brain masked by a bone barrier comprising at least a portion of a skull surrounding said brain, by causing sound signals to be emitted by at least one array of transducers through said bone barrier,

the method ~~being characterized in that it comprises~~ comprising:

a training stage comprising at least the following steps:

1a) making a three-dimensional image of the bone barrier, at least in part by using X-rays, thereby obtaining a parameter representative of the porosity of said bone barrier

at various points;

1b) from said three-dimensional image, determining three-dimensional maps of at least density, soundwave speed, and soundwave absorption in said bone barrier;

1c) determining a specific position for the array of transducers relative to the bone barrier;

1d) simulating at least one propagation of soundwaves between at least one point of the substantially homogeneous medium and at least some of the transducers of the array of transducers on the basis of a mathematical model of propagation and said three-dimensional maps of density, soundwave speed, and soundwave absorption; and

1e) on the basis of said simulation, calculating individual sound signals to be emitted by at least some of the transducers of said array of transducers in order to obtain said target soundwave field;

and a stage of actually positioning the array of transducers on the brain barrier, this stage comprising the following steps:

2a) initially positioning the array of transducers on the bone barrier [[(14)]] approximately in the specific position;

2b) using at least some of the transducers of the array of transducers to perform echography to locate the position of said array of transducers relative to the bone barrier; and

2c) refining the position of the array of transducers relative to said bone barrier as a function of the location determined in step 2b)<u>; and</u>

<u>an imaging stage during which at least one echographic image of the substantially homogenous medium is made using at least a portion of the array of transducers, using the individual sound signals as determined during the training stage</u>.

6. (Previously presented) A method according to claim 5, in which the soundwaves are at frequencies lying in the range 0.5 MHz to 3 MHz.

7. (Currently amended) A method according to claim 5, in which step 1e) is followed by a step 1f) during which emission of sound signals by the array of transducers is simulated, said signals being determined from said individual sound signals and serving to

obtain a desired soundwave field, propagation of soundwaves generated by said emission is simulated, and ~~it is~~ verified that said propagation satisfies certain predefined criteria.

8. (Currently amended) A method according to claim 5, in which:

during step 1d), propagation of soundwaves from at least one point [[(18)]] in the substantially homogeneous medium towards at least some transducers of the array of transducers is simulated, and received simulated sound signals Ri(t) reaching the locations of said transducers i of the array of transducers are determined, where i is an integer in the range 1 to n, and n is the number of transducers in the array of transducers; and

during step 1e), the individual sound signals Ei(t) for emission by each transducer i under consideration are determined as being proportional to a time reversal Ri(t) of said received simulated sound signals Ri(t) as previously determined in step 1d).

9. (Currently amended) A method according to claim 8, in which, during step 1e), the sound signals Ei(t) to be emitted are determined by the formula:

~~Ei(t)=Gi.multid- ot.Ri(t)~~ <u>Ei(t) = Gi.Ri (-t)</u>

where Gi is a gain factor that differs from one transducer i to another, for compensating dissipation in the bone barrier.

10. (Original) A method according to claim 9, in which the gain factors Gi corresponding to at least some of the transducers are respectively inversely proportional to the square of an amplitude of the corresponding received simulated sound signals Ri(t).

11. (Currently amended) A method according to claim 8, in which:

during step 1d), the simulation is performed by using a virtual three-dimensional map of soundwave absorption, having absorption coefficients ~~.quadrature.~~ <u>-τ</u> at each point of the bone barrier that are opposite to the real absorption coefficients ~~.quadrature.~~ <u>–τ</u> determined during step 1b); and

during step 1e), the individual sound signals Ei(t) to be emitted are determined as being equal to said time reversal Ri(t).

12. (Currently amended) A method according to claim 7, in which the array of transducers is included in a fluid-filled tank having at least one flexible wall for pressing against the bone barrier, the specific positions of the transducers as determined during step 1c) not being in contact with the bone barrier, and in which:

during step 1d):

propagation of soundwaves from at least one point of the substantially uniform medium towards at least some transducers of the array of transducers is determined, and received simulated sound signals Ri(t) reaching the locations of said transducers i of the array of transducers are determined, where i is an integer in the range 1 to n, and where n is the number of transducers in the array of transducers;

then emission by each transducer i of a sound signal Ri(t) corresponding to a time reversal of the signal Ri(t) is simulated, and propagation in said fluid to a virtual transducer i situated in contact with the bone barrier in correspondence with the transducer i is simulated, and received simulated sound signals R'i(t) reaching the location of said virtual transducer i are determined;

then emission by each virtual transducer i of an acoustic signal ~~G'i.multidot.R'i(t)~~ <u>G'i.R'i(-t)</u> is simulated where R'i(t) is a time reversal of the signal R'i(t) and where G'i is a reversal coefficient proportional to the square of an amplitude of the signal R'i(t), at least for some of the virtual transducers i;

then propagation in said fluid to the transducer i is simulated and received simulated sound signals R"i(t) reaching the location of said transducer i are determined;

and during step 1e), the individual sound signals Ei(t) to be emitted are determined as being equal to a time reversal R"i(t) of said received simulated sound signals R"i(t).

13. (Currently amended) A method according to claim 7, in which during step 1d), the emission of a soundwave pulse by at least some of the transducers i of the array of transducers is simulated and propagation of soundwaves from each transducer i in consideration towards a plurality of reference points r situated in the substantially uniform medium is simulated, where i is an index in the range 1 to n designating a transducer of the array, and where n is a non-zero natural integer designating the number of transducers, r being an integer in the range 1 to m, where m is a non-zero natural integer designating the number of reference points, and simulated impulse responses hri(t) reaching each of said

reference points r of the substantially homogeneous medium are determined, step 1e) comprising the following substeps:

1e1) determining a number [[p]] p of frequency components for each of the simulated impulse responses, having respective frequencies ~~.quadrature.k~~ $\underline{\omega k}$ where k is an index lying in the range 1 to[[p]] p and designating a frequency component;

1e2) determining[[p]] p transfer matrices ~~H(.quadrature.k)=[Hri(.quadrature.k)~~ $\underline{H(\omega k) = [Hri(\omega k)]}$, i lying in the range 1 to n, and r going from 1 to m where ~~Hri(.quadrature.k)~~ $\underline{[Hri(\omega k)]}$ is the value at the frequency .~~quadrature.k~~ $\underline{\omega k}$ of the Fourier transform of the impulse response Hri(t); and

1e3) for each reference point r, n components Ei~~(.quadrature.k,r)~~$\underline{(\omega k, r)}$ are determined such that:

~~F(.quadrature.k,r)=H(.quadrature.k).multidot.E(.quadrature.k,r)~~

$\underline{F(\omega k, r) = H(\omega k)E(\omega k, r)}$

where ~~E(.quadrature.k,r)=[Ei(.quadrature.k,r)~~] $\underline{E(\omega k, r) = [Ei(\omega k, r)]}$ is a vector having n components Ei~~(.quadrature.k,r)~~$\underline{(\omega k, r)}$, ~~F(.quadrature.k,r)=[F.quadrature.(.quadrature.k,r)]~~ $\underline{F(\omega k, r) = [F\ell(\omega k, r)]}$ is a vector having m components ~~F.quadrature.(.quadrature.k,r)~~ $\underline{F\ell(\omega k, r)}$ where ~~.quadrature.~~ $\underline{\ell}$ varies in the range 1 to m, these m components ~~F.quadrature.(.quadrature.k,r)~~ $\underline{F\ell(\omega k, r)}$ corresponding to generating said predetermined target soundwave field at the frequency ~~.quadrature.k~~ $\underline{\omega k}$ at the points r.

14. (Currently amended) A method according to claim 13, in which, during substep 1e3), [[p]] p matrices ~~H-1(.quadrature.k)~~ $\underline{H^{-1}(\omega k)}$ are calculated at least by inverting the transfer matrices ~~H(.quadrature.k)~~ $\underline{H(\omega k, r)}$, and for each reference point r of the substantially homogeneous medium, the vector ~~E(.quadrature.k,r)~~ $\underline{E(\omega k, r)}$ is calculated using the formula:~~E(.quadrature.k,r)=H-1(.quadrature.k).multid ot.F(.quadrature.k,r)~~

$\underline{E(\omega k, r) = H^{-1}(\omega k).F(\omega k, r)}$

15. (Previously presented) A method according to claim 1, in which, during step 1d), the impulse responses hir(t) between a plurality of reference points r of the substantially homogeneous medium and at least some of the transducers i of the array of transducers are determined, where i is an index in the range 1 to n which designates a transducer, and where n is a non-zero natural integer which designates the number of transducers, r being an integer lying in the range 1 to m, m being a non-zero natural integer designating the number of reference points, and during step 1e), it is also determined how to focus at least a portion of the array of transducers in reception on each reference point r in order to make an echographic image.

16. (Canceled)

17. (Currently amended) Apparatus ~~specifically designed for implementing a method according to any preceding claim,~~ for non-invasively obtaining at least one predetermined target soundwave field in a substantially homogeneous medium comprising at least a portion of a brain masked by a bone barrier comprising at least a portion of a skull surrounding said brain, the apparatus comprising at least:

an array of transducers adapted to be positioned outside a bone barrier masking a substantially homogeneous medium;

mapper means for determining three-dimensional maps of at least density, soundwave speed, and soundwave absorption in the bone barrier, on the basis of a three-dimensional image of said bone barrier made by X-rays and giving the porosity of said bone barrier at each point;

simulator means for simulating at least one propagation of soundwaves between at least one point of the substantially homogeneous medium and at least some of the transducers of the array of transducers on the basis of a mathematical model of propagation and on the basis of said three-dimensional maps of density, of soundwave speed, and of soundwave absorption, and as a function of a specific position for the array of transducers relative to the bone barrier;

calculator means for responding to said simulation to calculate individual sound signals to be emitted by at least some of the transducers of said array of transducers in order

to obtain [[a]] the at least one predetermined target soundwave field in the substantially homogeneous medium;

locator means for using at least some of the transducers of the array of transducers to locate [[the]] an initial position of said array of transducers [[and]] relative to the bone barrier by echography, the initial position an approximation of the specific position; and

position-refiner means for refining [[an]] the initial position of the array of transducers relative to the bone barrier as a function of the position of the array of transducers as located relative to the bone barrier in such a manner that the position of the array of transducers relative to the bone barrier corresponds to the specific position.

18. (Previously presented) Apparatus according to claim 17, in which the means for locating the position of said array of transducers relative to the bone barrier are adapted to determine an outside shape of at least a portion of the bone barrier by echography, using at least a portion of said array of transducers, by comparing said outside shape with said three-dimensional image of said bone barrier.

19. (Previously presented) Apparatus according to claim 17, comprising a locating device provided with securing means adapted to secure said locating device rigidly on the bone barrier, said locating device being adapted to absorb X-rays and being visible in the three-dimensional image of said bone barrier, and the means for locating the position of said array of transducers relative to the bone barrier are adapted to locate the position of the array of transducers relative to the locating device by echography.

20. (Previously presented) Apparatus according to claim 17, in which the array of transducers is included in a fluid-filled tank having at least one flexible wall for pressing against the bone barrier.

21. (Previously presented) Apparatus according to claim 17, in which the array of transducers comprises both a sub-array for imaging and a sub-array for hyperthermia treatment, these two sub-arrays comprising transducers of respective different types.

22. (Previously presented) Apparatus according to claim 17, in which the array of transducers is adapted to emit soundwaves at frequencies lying in the range 0.5 MHz to 3 MHz.

23. (Previously presented) Apparatus according to claim 17, further comprising simulator means adapted:

to simulate at least the array of transducers emitting sound signals determined from said individual sound signals and enabling a desired soundwave field to be obtained;

to simulate propagation of soundwaves generated by said emission; and

to verify that said propagation satisfies certain predefined criteria.

24. (Previously presented) Apparatus according to claim 17, in which:

the simulator means are adapted to simulate soundwave propagation from at least one point of the substantially homogeneous medium towards at least some of the transducers of the array of transducers to determine received simulated sound signals Ri(t) reaching the locations of said transducers i of the array of transducers, i being an integer in the range 1 to n, and n being the number of transducers in the array of transducers; and

the calculator means are adapted to determine the individual sound signals Ei(t) to be emitted by each transducer i under consideration as being proportional to a time reversal Ri(t) of said received simulated sound signals Ri(t) as previously determined in step 1d).

25. (Currently amended) Apparatus according to claim 24, in which the calculator means are adapted to determine the sound signals Ei(t) to be emitted using the formula:

~~Ei(t)=Gi.multidot.Ri(t)~~ Ei(t).Ri(t)

where Gi is a gain factor that differs from one transducer i to another, in order to compensate for dissipation in the bone barrier.

26. (Original) Apparatus according to claim 25, in which the gain factors Gi corresponding to at least some of the transducers are respectively inversely proportional to the square of an amplitude of the corresponding received simulated sound signals Ri(t).

27. (Currently amended) Apparatus according to claim 24, in which:

the simulator means are adapted to perform said simulation of soundwave propagation by using a virtual three-dimensional map of soundwave absorption having at each point of the bone barrier absorption coefficients of ~~.quadrature.~~ -τ opposite to the real absorption coefficient ~~.quadrature.~~ -τ as determined during step 1b); and

the calculator means are adapted to determine the individual sound signals Ei(t) to be emitted as being equal to said time reversal Ri(t).

28. (Currently amended) Apparatus according to claim 17, in which the array of transducers is included in a fluid-filled tank having at least one flexible wall for pressing against the bone barrier, the locations provided for the transducers taken into account by the simulator means not being in contact with the bone barrier,

in which apparatus the simulator means are adapted:

to simulate propagation of soundwaves from at least one point of the substantially homogeneous medium towards at least some of the transducers of the array of transducers and to determine the received simulated sound signals Ri(t) reaching the locations of said transducers i of the array of transducers, i being an integer in the range 1 to n, and n being the number of transducers in the array of transducers;

to simulate emission by each transducer i of a soundwave Ri(t) corresponding to a time reversal of the signal Ri(t), and to simulate propagation in said fluid to a virtual transducer i situated in contact with the bone barrier ~~(14)~~ in correspondence with the transducer i, and to determine the received simulated sound signals R'i(t) reaching the location of said virtual transducer i;

to simulate emission by each virtual transducer i of a sound signal ~~G'i.multidot.R'i(t)~~ <u>G'i.R'(t)</u> where R'i(t) is a time reversal of the signal R'i(t), and where G'i is a reversal coefficient proportional to the square of an amplitude of the signal R'i(t), at least for some of the virtual transducers i; and

to simulate propagation in said fluid to the transducer i, and to determine the received simulated sound signals R"i(t) reaching the location of said transducer i;

and in which the calculator means are adapted to determine the individual sound signals Ei(t) to be emitted as being equal to a time reversal R"i(t) of said received simulated sound signals R"i(t).

29. (Currently amended) Apparatus according to claim 17, in which the simulator means are adapted:

to simulate emission of a soundwave pulse by at least some of the transducers i of the array of transducers, and propagation of soundwaves from each transducer i in question towards a plurality of reference points r situated in the substantially homogeneous medium, i being an index in the range 1 to n designating a transducer of the array, and n being a non-zero natural integer designating the number of transducers, r being an integer in

the range 1 to m, and m being a non-zero natural integer designating the number of reference points;

to determine simulated impulse responses hri(t) reaching each of said reference points r of the substantially homogeneous medium;

and in which the calculator means are adapted:

to determine a number[[p]] p of frequency components for each of said simulated impulse responses at respective frequencies ~~.quadrature.k~~ ωk, k being an index in the range 1 to[[p]] p and designating a frequency component

to determine[[p]] p transfer matrices ~~H(.quadrature.k)=[Hri(.quadrature.k)]~~ $H(\omega k)=[Hri(\omega k)]$, i lying in the range 1 to n and r lying in the range 1 to m, where Hri~~(.quadrature.k~~ ωk is the value at the frequency ~~.quadrature.k~~ ωk of the Fourier transform of the impulse response Hri(t);

and to determine, for each reference point r, n components Ei~~(.quadrature.k,r)~~ $(\omega k, r)$ such that:

~~F(.quadrature.k,r)=H(.quadrature.k).multido t.E(.quadrature.k,r)~~

$$F(\omega k, r) = H(\omega k).E(\omega k, r)$$

where ~~E(.quadrature.k,r)=[Ei(.quadrature.k,r)]~~ $E(\omega k, r) = [Ei(\omega k, r)]$ is a vector having n components Ei~~(.quadrature.k,r)~~ $(\omega k, r)$, ~~F(.quadrature.k,r)=[F.qua drature.(.quadrature.k,r)]~~ $F(\omega k, r) = [F\ell(\omega k, r)]$ is a vector of m components ~~F.quadrature.(.quadrature.k,r)~~ $F\ell(\omega k, r)$ where ~~.quadrature.~~ ℓ lies in the range 1 to m, these m components ~~F.quadrature.(.quadrature.k,r)~~ $F\ell(\omega k, r)$ corresponding to generating said predetermined target soundwave field at the frequency ~~.quadrature.k~~ ωk at the points r.

30. (Currently amended) Apparatus according to claim 29, in which the calculator means are adapted:

to calculate[[p]] p matrices ~~H-1(.quadrature.k)~~ $H^{-1}(\omega k)$ at least by inverting the transfer matrices of ~~H(.quadrature.k)~~ $H(\omega k)$; and

for each reference point r of the substantially homogeneous medium, to calculate the

vector ~~E(.quadrature.k,r)~~ $\underline{E(\omega k, r)}$ by means of the formula:

~~E(.quadrature.k,r)=H-1(.quadrature.k).multidot.F(.quadrature.k,r)~~

$$\underline{E(\omega k, r) = H^{-1}(\omega k).F(\omega k, r)}$$

31. (Currently amended) Apparatus according to claim 17, in which the simulator means [[7]] are adapted:

to determine the impulse responses hir(t) between a plurality of reference points r of the substantially homogeneous medium and at least some of the transducers i of the array of transducers, i being an index lying in the range 1 to n designating a transducer, and n being a non-zero natural integer designating the number of transducers, r being an integer lying in the range 1 to m, and m being a non-zero natural integer designating the number of reference points;

and in which the calculator means are adapted to determine how to focus at least a portion of the array of transducers in reception on each reference point r in order to make an echographic image.

32. (Previously presented) Apparatus according to claim 17, further comprising imaging means adapted to make at least one echographic image of the substantially homogeneous medium using at least a portion of the array of transducers, using the individual sound signals determined by the calculator means.